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Cost analysis of inter-depot transportation options for U.S. Navy east coast air-launched missiles

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THESIS

COST ANALYSIS OF INTER-DEPOT TRANSPORTATION OPTIONS FOR U.S. NAVY EAST COAST AIR-LAUNCHED MISSILES

by

Charles L. Sellers

September 1998

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Since the disintegration of the Warsaw Pact and the Soviet Union, the Department of Navy has had to learn how to meet its commitments with an ever-decreasing budget. One Navy community addressing this downsizing is the east coast ordnance community. Because of restructuring and the closure of Weapon Station Charleston, South Carolina, the remaining weapon stations are handling the same amount of ordnance with fewer personnel. As a result of the restructuring, the aircraft carriers, ordnance ships, and large deck amphibious ships conduct ordnance transfers at Naval Weapon Station (NWS) Earle, New Jersey. These ships all carry air-launched missiles that have to be maintained at Naval Weapons Station Yorktown. This thesis develops cost equations associated with several different methods of transportation (commercial and Department of Defense). These equations are used to generate cost curves for each of four types of missiles being transported between NWS Earle and NWS Yorktown. The curves are analyzed, and decision policies are determined which ensure the most cost effective method of transportation is being used to transport the missiles.

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COST ANALYSIS OF INTER-DEPOT TRANSPORTATION OPTIONS FOR U.S. NAVY EAST COAST AIR-LAUNCHED MISSILES

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requirements for the degree of

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ABSTRACT

Since the disintegration of the Warsaw Pact and the Soviet Union, the Department of Navy has had to learn how to meet its commitments with an ever-decreasing budget. One Navy community addressing this downsizing is the east coast ordnance community. Because of restructuring and the closure of Weapon Station Charleston, South Carolina, the remaining east coast weapon stations are handling the same amount of ordnance with fewer personnel. As a result of the restructuring, the aircraft carriers, ordnance ships, and large deck amphibious ships conduct ordnance transfers at Naval Weapon Station (NWS) Earle, New Jersey. These ships all carry air-launched missiles that have to be maintained at Naval Weapons Station Yorktown. This thesis develops cost equations associated with several different methods of transportation (commercial and Department of Defense). These equations are used to generate cost curves for each of four types of missiles being transported between NWS Earle and NWS Yorktown. The curves are analyzed, and decision policies are determined which ensure the most cost-effective method of transportation is being used to transport the missiles.

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LIST OF ACRONYMS

ACC	Ammunition Condition Code
AE	Auxiliary Ordnance ship
AOE	Auxiliary Multiproduct ship
BRAC	Base Realignment and Closure
CINCLANTFLT	Commander, U.S. Naval Forces Atlantic
CV	Aircraft Carrier (non-nuclear propulsion)
CVN	Aircraft Carrier (nuclear propulsion)
DoD	Department of Defense
DoN	Department of the Navy
HE	High Explosive
ISO	International Standards Organization
JORD MOVEX	Joint Ordnance Movement Exercise
LHA	Amphibious Assault Ship (General Purpose)
LHD	Amphibious Assault Ship (Multipurpose)
MDD	Maintenance Due Date
MSC	Military Sealift Command
NOB	Naval Operational Base
NWS	Naval Weapons Station
RSS&I	Receipt, Securing, Storage, and Inspection
SWT	Service Worldwide Transportation

EXECUTIVE SUMMARY

Since the disintegration of the Warsaw Pact and the Soviet Union, the Department of the Navy has had to learn how to meet its commitments with an ever-decreasing budget. One Navy community addressing this downsizing is the east coast ordnance community. These personnel are charged with managing approximately half of the Navy's ordnance inventory. They have to ensure that ships preparing for deployment have the proper ordnance load out, and they have to offload the ordnance once the ships return from deployment.

Because of restructuring and the closure of Weapon Station Charleston, SC, the remaining east coast weapon stations are handling the same amount of ordnance with fewer personnel. Also, as a result of the restructuring, the aircraft carriers, ordnance ships, and large deck amphibious ships conduct ordnance transfers at Naval Weapon Station (NWS) Earle, NJ. These ships all carry air-launched missiles, i.e., Harpoon, Phoenix, Sparrow, and Sidewinder. Even though these missiles are stored, loaded, and offloaded at NWS Earle there is no maintenance facility at Earle. When maintenance has to be conducted on the four types of missiles they have to be transported to NWS

Yorktown, VA. The current method of transportation is via commercial trucks with 48-foot flatbeds.

This thesis analyzes the current and alternative possible transportation methods. The other methods are commercial trucks with 20-foot End-opening containers, commercial rail with 20-foot End-opening containers, commercial rail boxcars, U.S. Army LSVs (Logistic Support Vessels), and U.S. Navy AOEs (ordnance ships). The first part of the analysis develops equations which are used to calculate the total cost to transport a given number of missiles using a given transportation method. Once the equations are developed they are used to generate cost curves. These curves show the cost incurred to transport the missiles, for a given range of missiles (1 to a designated maximum). For each type of missile, a curve is generated for each transportation method. Once all the curves are generated they are compared graphically and numerically to determine decision policies. These policies give the ordnance manager the ability to determine the best method of transportation given the number of missiles that need to be transported. In all there are eight separate decision policies generated, one for each missile type being transported from NWS Earle to NWS Yorktown, and one for each missile type being transported from NWS Yorktown to NWS Earle.

The results of the analysis show that in a majority of all the eight decision policies the commercial transportation methods cost the least to transport missiles. In only one case does a DoD transportation method become feasible. This occurs when Harpoons are to be transported south from NWS Earle to NWS Yorktown. AOEs are not a feasible option in any of the eight missile/direction decision policies.

There are three conclusions of this analysis. The first is that commercial transportation methods are the most cost effective. The second is that LSVs should generally not be utilized as a pure cost saving method of transportation. They may become a more feasible option when other benefits of using this asset are weighed into the decision process, i.e., training for both Army and Navy units. The final conclusion is that AOEs should not be utilized as a means of transporting missiles when there is another method available.

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I. INTRODUCTION

A. PROBLEM CONTEXT

Since the disintegration of the Warsaw Pact and the Soviet Union in the late 1980's and early 1990's, the Department of the Navy (DoN) has been going through a time of transition. It has seen its fleets reduced from a large armada of 600 ships to a compact force of almost 300 ships. Along with the decommissioning of many ships the Navy has closed several of its major bases. Every part of the Navy has had to learn how to do more with less money. Each officer, enlistee, and civilian has had to become smarter in the way he or she utilizes available funds.

One of the communities that has had to address downsizing is the Navy's Ordnance community. It lost one of its three east coast weapons stations. The Naval Weapons Station (NWS) Charleston, South Carolina was closed as part of the 1993 round of the Base Realignment and Closure (BRAC) process. The two remaining east coast NWSs, at Earle, NJ and Yorktown, VA, have had to absorb Charleston's work in addition to significantly reducing personnel. The remaining personnel are charged with managing approximately half of the Navy's $38 billion ordnance inventory. [Ref. 1] They have had to ensure that ships preparing for deployment have the proper ordnance load out, and they have to offload the ordnance once the ships return from deployment.

Prior to the closing of NWS Charleston, the ammunition transfers were conceptually simple. All the AE/AOE's would transfer at Earle; the large deck amphibious ships (LHD's and LHA's) would transfer munitions to barges while at anchorage at Naval Station Norfolk, Virginia; all the other smaller combatants (cruisers, destroyers, frigates, and small deck amphibious ships, etc.) were dispersed between Earle, Yorktown, and Charleston; and the carriers transferred munitions from/to an AE/AOE while at sea. After NWS Charleston closed, the ships that had previously conducted ordnance transfers there had to go to one of the two remaining east coast weapons stations to execute the transfers. Also, the LHD and LHA ordnance transfers were moved to Earle due to the high costs of anchorage at Norfolk. Presently all AE/AOE's, LHD's, LHA's, and

CV/CVN's[1] conduct ordnance transfers at Earle while the remaining non-deployed Atlantic Fleet ships conduct ordnance transfers at Yorktown.

The carriers, large-deck amphibious ships, and the ordnance ships depend on NWS Earle to provide the ordnance necessary for deployment. Since much of the ordnance carried by these ships is expensive to procure, it is more cost effective to repair the ordnance as needed in order to extend the missiles' life. Some of the most expensive ordnance carried by these ships are air-launched missiles. Since NWS Earle has no maintenance capabilities, the air-launched missiles have to be shipped to other facilities for maintenance. Some of the missiles are shipped back to the manufacturer, some are shipped to Department of Defense (DoD) facilities throughout the United States, and some are shipped to Yorktown, which has the only ordnance maintenance facility on the east coast. After they are repaired, most of these missiles must be shipped back to NWS Earle.

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[1] While carriers actually conduct ordnance transfers with AOE's at sea, they are counted as being conducted at Earle because that is where the AOE's on/off-load ordnance.

Currently, 48-foot flatbed commercial trucks are used for transferring missiles between NWS Earle and NWS Yorktown. The Navy does not have organic trucking assets available to conduct in-house transportation of the missiles and must rely on the commercial sector to meet its transportation needs. The current process will be discussed in greater detail in Chapter II.

B. PROBLEM STATEMENT

The Navy's Ordnance community does not use any type of modeling technique to determine when to ship missiles and how many to send. The decisions are made purely on a reactive basis. Additionally, there has been no cost comparison of alternative transportation methods to ensure that the current practice is indeed the most cost effective manner of transportation. While on experience tour at the CINCLANTFLT Ordnance Office, during November and December of 1997, the author was asked to investigate which method of transporting air-launched missiles would be the most cost effective.

This thesis analyzes these issues. It suggests alternative transportation methods and then answers the question of which method of transportation is the most cost effective to use. The transportation alternatives suggested include the current commercial truck, rail car, intermodal container on truck or rail, Navy ordnance ships (AOEs), and opportunity lifts from Army watercraft. To answer the question, the analysis occurs in two steps.

The first step focuses on the individual methods of transportation and the processes required to transport missiles between NWS Earle and NWS Yorktown. For each method, the different steps of the process are listed and described. Costs for each step within each process are determined and cost equations for each transportation method are formulated.

The second step of the analysis takes the cost equations for each transportation method and calculates the cost per missile (for each missile type). For each missile type, i.e., Harpoon, Phoenix, Sidewinder, and Sparrow, cost curves for each method are generated and compared to determine the decision policy to be utilized when determining which transportation method will be most cost effective to transport a given number of missiles. The two steps of analysis are further discussed in Chapter III.

C. THESIS OVERVIEW AND ORGANIZATION

This thesis consists of five chapters. Chapter II describes the missiles being transported, the current and other possible methods of transportation, and discusses basic costs incurred when transporting ordnance. Chapter III discusses the construction of the cost equations. Chapter IV discusses the results of the analysis. Finally, Chapter V provides a summary and conclusions.

II. BACKGROUND

This chapter provides background information concerning the transportation of air-launched missiles between NWS Earle and NWS Yorktown. It first describes the use, history, and capabilities of the four missile types maintained at NWS Yorktown. The current process is then described, followed by the processes associated with the other possible transportation methods, including some being considered by CINCLANTFLT Ordnance Logistics personnel. Basic costs incurred when moving ordnance are discussed in the last portion of the chapter.

A. MISSILE TYPES

Currently only four of the many different air-launched missiles are being shipped to NWS Yorktown for maintenance. These are the AIM-7 Sparrow, the AIM-9 Sidewinder, the AIM-54 Phoenix, and the AGM-74 Harpoon.

The AIM-7 Sparrow is a medium-range, radar-guided, air-to-air missile. The development of the missile commenced with the Sparrow 1 program in 1946. The Sparrow 2 program was started in 1955 but was canceled in 1958, and the current missile, the Sparrow 3, program development started in 1955 with the AIM-7C Sparrow entering service in the Navy in 1958. Since entering service the missile design has gone through several changes, most of which have dealt with the missile's guidance, propulsion, warhead, and counter-measure capabilities. The most current version of the missile is the AIM-7P, with the AIM-7R in development. The current version uses a semi-active radar to home in on its target. The aircraft firing the missile illuminates the target with its onboard radar, and the missile follows the radar returns to the target. The missile is approximately 3.66 meters long, has a launch weight of 230 kilograms, has a 39 kilogram High Explosive (HE) blast/fragmentation warhead, and has a range of 45 kilometers. [Ref. 2] It is currently carried on the Navy's F-14 Tomcat and F/A-18 Hornet. Also, a shipboard version of the Sparrow has been developed as a surface-to-air anti-aircraft defense missile. (See Figure 1)

The AIM-9 Sidewinder is a short range, infrared guided, air-to-air missile. Development of the Sidewinder program started in the late 1940's. The first generation of the missile, the AIM-9B, entered service in 1956. The missile system has gone through several developmental changes over the years, with the AIM-9M and AIM-9S being the most current versions in the fleet. The main difference between the 9M and 9S is that the 9S contain a slightly larger warhead. All the versions of the Sidewinder use an Infrared guidance system that homes in on the exhaust emitted from the target aircraft. The missile is approximately 2.87 meters long, weighs 87 kilograms, has a 10 kilogram HE fragmentation warhead, and has a range of 8 kilometers. [Ref. 3] It is carried on the Navy's F-14 Tomcat, F/A-18 Hornet, and the Marine Corps AV-8B Harrier. The Air Force has developed an air-to-air version of the Sidewinder, and the Army developed the MIM-72 Chaparral which is a surface-to-air variant of the Sidewinder. (See Figure 1)

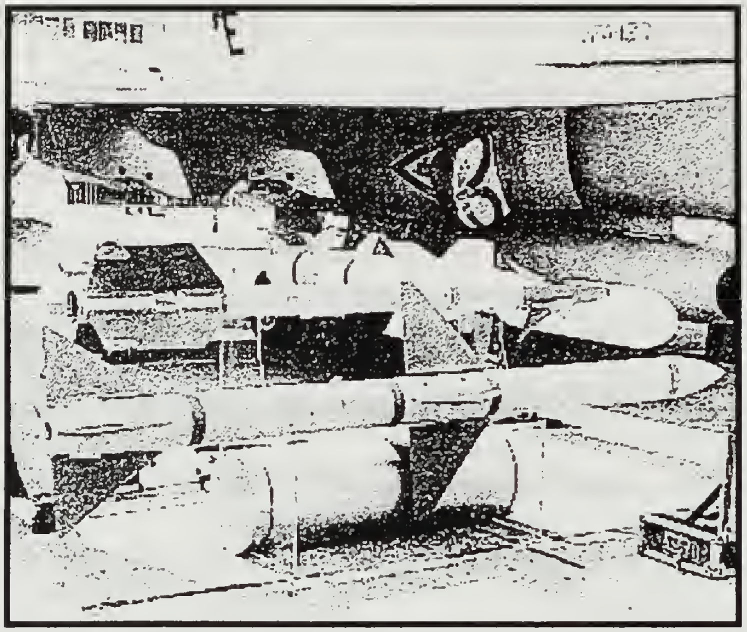

Figure 1. Size comparison of Sparrow (foreground), Sidewinder (Middle), and Harpoon (rear). [Ref. 2]

The AIM-54 Phoenix is a long-range, radar-guided, air-to-air missile. The development of the missile commenced in 1960 with production starting in 1972. The first missiles were delivered to the fleet in 1974. The latest version, the AIM-54C, entered the fleet in 1985. During the height of the Cold War, the Phoenix was utilized as the first line of defense for an U.S. aircraft carrier against attacking Soviet aircraft. The missile uses semi-active radar during mid-course flight and uses onboard active radar during the terminal phase of flight. It is approximately 3.96 meters long, weights 463 kilograms, has a 60-kilogram HE Continuous Rod warhead, and has a range of 150 kilometers. [Ref. 5] The only Naval aircraft that carries the Phoenix is the F-14 Tomcat. (See Figure 2)

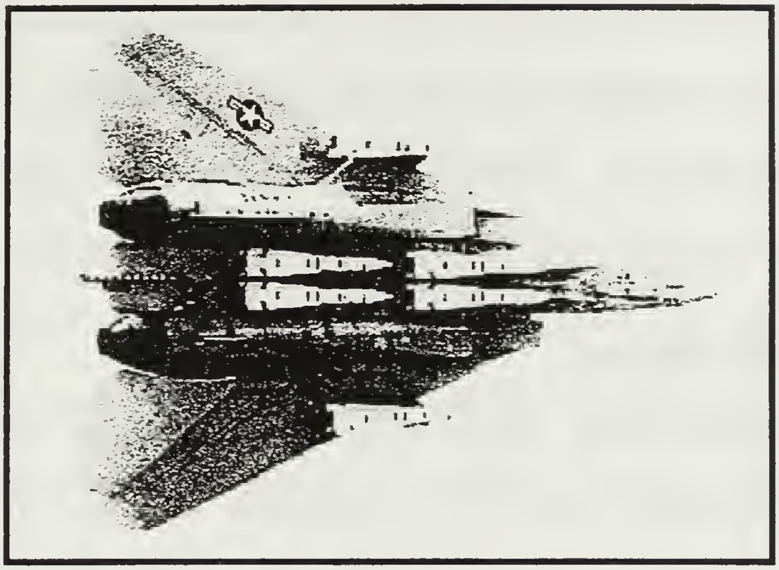

Figure 2. F-14 carrying six Phoenix missiles. [Ref. 4]

The AGM-54A Harpoon is a long-range, radar and infrared guided, air-to-surface missile. It was designed to be an air-launched anti-ship missile to offset the growing threat of destroyers, submarines, and fast patrol boats equipped with anti-ship missiles. The development of the missile started in 1971 with the first missile entering the fleet in 1977. Shipboard and submarine versions of the missile have also been developed and are in service. The air-launched version of the missile utilizes active radar to locate and home in on a target. The warhead is designed to delay explosion until it has penetrated the hull of the target ship to allow for optimal destruction. It can be carried on the Navy's F/A-18 Hornet. The missile is approximately 3.85 meters long, weights 556 kilograms, uses a 222 kilogram HE Blast Penetration warhead, and has a range of 120 kilometers. [Ref. 7] (See Figure 1)

B. CURRENT PROCESS

The three ship types that carry the majority of the four air-launched missiles discussed earlier are the AE, AOE, and CV/CVN. The large-deck amphibious ships (LHD and LHA) carry only the Sidewinders and in quantities much less than the ordnance ships and carriers. All of the AE's are in the process of being decommissioned and transferred to the Military Sealift Command (MSC). There are no current plans to have the AE's deploy with battlegroups. The last of the east coast AE's, the USS SANTA BARBARA, conducted her final deployment in early 1998. Because of this only the four Atlantic Fleet AOE's are considered in this thesis.

When a carrier battlegroup deploys, an AOE accompanies it. It is the AOE's responsibility to provide fuel, ordnance, and limited stores to the ships in the battlegroup. Prior to deployment the AOE receives its initial load of ordnance known as the Delta ordnance load. This is the load which is used to replenish the carrier and other ships.

A non-deploying AOE is utilized to transport ordnance to the carrier preparing for deployment. The carrier will receive part of its Bravo load prior to work-up Exercises and will receive the remaining portion of its load-out just prior to deployment. The Bravo load is the carrier's initial load it carries to its area of deployment. Once the six-month deployment is completed the AOE that deployed with the battlegroup returns to homeport (Earle) and is designated the "ready ship" for a 30 day period. After the 30 days are up the ship can off-load its ordnance. When the carrier returns from deployment it remains the ready carrier (on call to deploy again if needed) until the carrier preparing for deployment has been certified as ready to deploy. Once the returning carrier is no longer the ready carrier it can offload its ordnance. The ordnance is transferred to a non-deployed AOE while at sea. The AOE then returns to Earle and offloads the ordnance.

The ordnance from returning carriers and AOEs eventually gets offloaded at Earle. At least 30 days prior to an offload occurring, NWS Earle generates a preliminary offload plan that details what ordnance is to be offloaded. After the preliminary offload plan has been developed the types of conveyances (rail car or truck) are determined and ordered. Approximately 2 weeks prior to the offload a pre-arrival conference, composed of NWS Earle Logistics Support Team and Waterfront Accountability Team members, takes place. At this time the ship provides a list of the ordnance to be offloaded and where the ordnance is located on the ship. This information allows personnel at NWS Earle to plan the offload sequence.

Once the ship arrives at NWS Earle the offload of ordnance begins. Whenever possible, a receipt inspection team boards the ship prior to the beginning of the offload and locates, inspects, and matches the ordnance with the lists previously provided by the ship. During this inspection the condition of the ordnance is confirmed, and once the condition is determined an Ammunition Condition Code (ACC) is given to the piece of ordnance. Air-launched missiles that receive an ACC of E, F, or G are deemed unserviceable and must be transferred to a maintenance facility. While the offload is taking place the foreman on the pier determines and orders the number of commercial trucks that are needed to ultimately transport missiles to Yorktown.

Current guidance for transporting missiles directs NWS Earle to transfer the following missiles to NWS Yorktown: Sparrows and Sidewinders if unserviceable or within 18 months of their Maintenance Due Date (MDD); all Phoenix's, whether serviceable or unserviceable; and all unserviceable Harpoons. [Ref. 8]

The current process for transferring missiles between Earle and Yorktown begins when the missiles are removed from the ship and placed on rail cars. These rail cars are owned by the weapons stations and used as material handling equipment to move ordnance to various locations on base. At the end of each day, the rail cars containing the air-launched missiles awaiting transfer to Yorktown via commercial truck are moved to a barricade area, which is approximately 17 miles from the pier. The barricade area consists of a set of covered magazines that are designed so the rail cars can pass through. When the commercial trucks arrive, the missiles are transferred from the rail cars to commercial trucks with 48-foot flatbeds. (See Figure 3) Once the missiles are secured to the flatbeds they are then transported to NWS Yorktown.

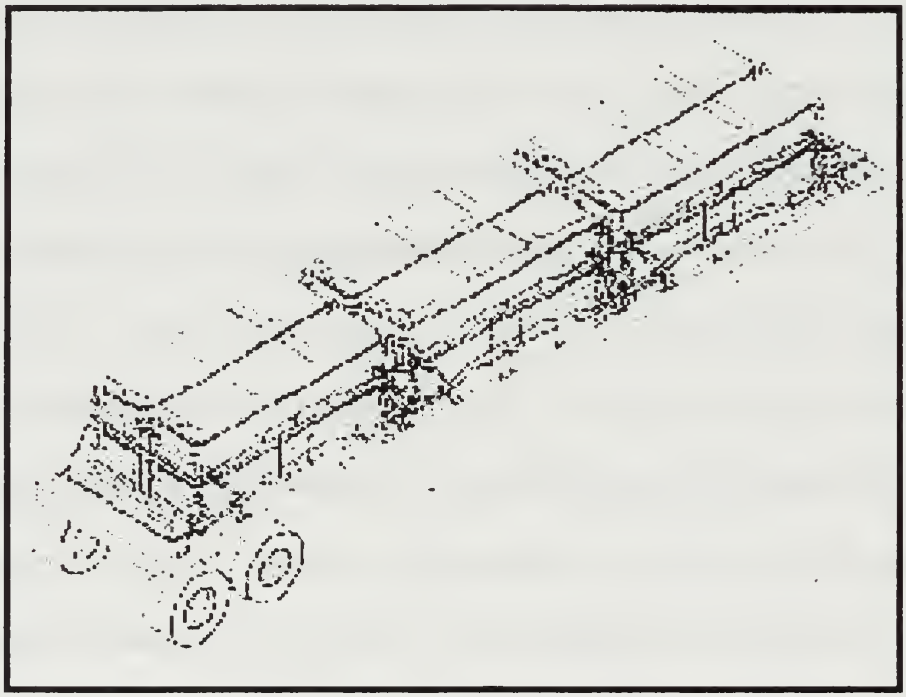

Figure 3. 48-Foot Flatbed loaded with 12 Phoenix missiles. [Ref. 7]

Upon arrival in Yorktown the missiles are removed from the flatbeds and placed in ordnance storage magazines. The missiles remain in the magazine until they are moved to the production facility. Once maintenance or repairs have been completed, the missile is placed back in the ordnance storage magazine.

At some point the repaired missiles are requested to be transported back to NWS Earle. These requests are generated for several reasons, including a Weapon Station Load Plan adjustment, shipfill, mission loads, or cargo loads. Once there is a request for missiles to be transported to NWS Earle the number of commercial trucks and 48-foot flatbeds are determined and ordered. The missiles are loaded onto the 48-foot flatbeds and then transported to Earle. Once the missiles arrive at Earle they are offloaded and placed either in storage magazines or loaded onto an awaiting ship.

C. OTHER POSSIBLE TRANSPORTATION METHODS

Having described the current process of transporting missiles from Earle to Yorktown, this section describes the five other possible transportation methods. These methods are commercial truck with containers, rail cars with containers, rail boxcars, U.S. Army LSVs, and U.S. Navy AOEs.

The first method, which is similar to the current method, utilizes commercial trucks but instead of using flatbeds, the missiles are stored in 20-foot ISO (International Standards Organization) End-opening containers. (See Figure 4) These containers are 8 feet high by 8 feet wide by 20 feet long, and are the same as standard commercial containers except that the door-end cornerposts are modified with angle iron to allow for the use of wooden dunnage without disturbing the force to the door. [Ref. 10] The containers have forklift pockets along the bottom so no specialized handling equipment is needed to move the containers. The transportation process in this case is very similar to the current process using 48-foot flatbed trucks except that instead of loading the missiles onto flatbeds at the barricade site, the missiles are loaded into containers on chassis. Once the missiles are loaded they can immediately leave for NWS Yorktown. The process for transporting the missiles north via 20-foot End-opening containers is the same as with 48-foot flatbed trucks. (See Figure 4)

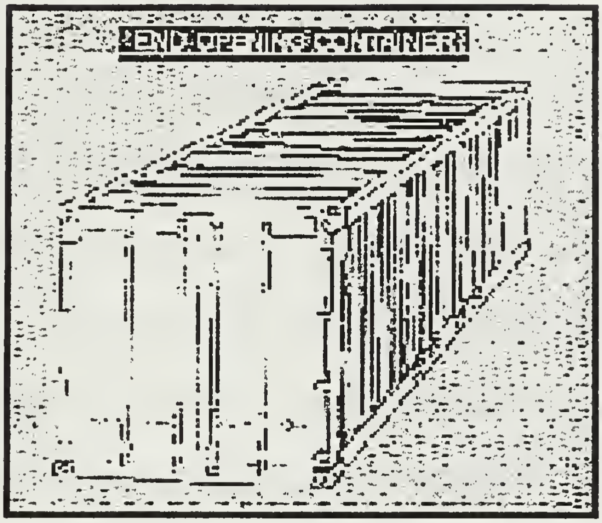

Figure 4. 20-foot End-opening Container. [Ref. 14]

The second method incorporates the 20-foot End-opening containers but instead of transporting the loaded containers via commercial trucks, the containers are placed on standard rail flatcars. With this process the containers have to be on the ground in order for missiles to be loaded or offloaded. Once the containers are loaded they are then placed on the flatcars using standard forklifts already available at the weapons stations. Four 20-foot containers can be placed on one rail flatcar. All of the other aspects pertaining to the process for transporting missiles via containers on rail flatcars remain the same as the previous processes.

The third possible method utilizes rail but the missiles are placed in standard commercial 50-foot, 6-inch boxcars. (See Figure 5) The boxcars are loaded at the barricade site at NWS Earle, transported to Yorktown, and offloaded to storage magazines at Yorktown. When missiles are scheduled to return to NWS Earle, the commercial boxcars are ordered; the missiles are then loaded onto the boxcars and transported back to Earle to be either offloaded to storage magazines or to a ship.

Even though both of the methods that utilize rail assets can theoretically go onto the pier and receive the missiles coming directly off the ship, this will not happen because it would lengthen the time required to offload the ship. The requirements for securing missiles for transport off the weapons stations are more stringent than for securing the missiles to the weapon station's rail cars for on-site movement. Because of these increased requirements it takes longer to load the containers or boxcars, which in turn slows down the offload process, thus causing the ship to remain pierside at Earle longer. As a general practice the weapons stations prefer to offload the ships as quickly as possible.

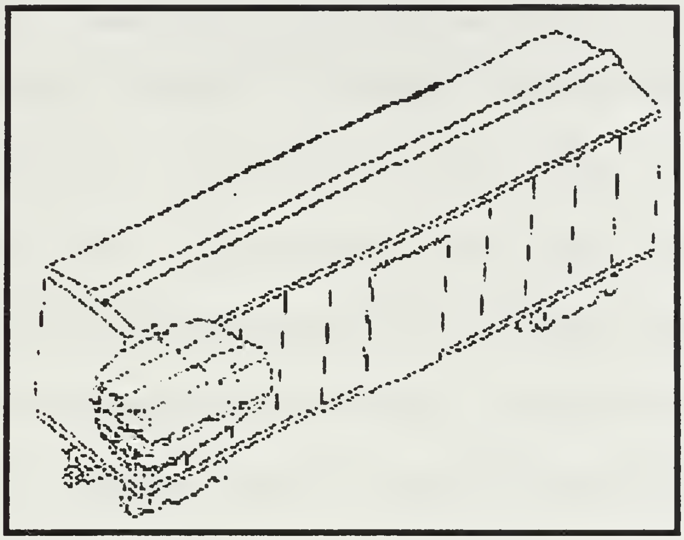

Figure 5. Standard commercial 50-foot, 6-inch boxcar. [Ref. 9]

In the fourth method instead of using commercial assets to transport the missiles, DoD assets are utilized. This method greatly modifies the transport process by utilizing AOEs (ordnance ships - see Figure 6) as shuttle ships to transfer the missiles. When ships offload missiles requiring further transfer to NWS Yorktown, the missiles would have to be placed in a magazine at NWS Earle to await the next shuttle AOE.

Once a quarter, an AOE not scheduled to deploy in the next six months will transfer all missiles headed for Yorktown and then return with all missiles requiring transfer from Yorktown to Earle. Once the AOE is loaded with the missiles heading for Yorktown, the AOE gets underway and travels south to Naval Operational Base Norfolk. The AOE does not actually go pierside at NWS Yorktown due to its size but anchors at Golf anchorage which is part of NOB Norfolk. The missiles destined for Yorktown are offloaded to barges, and missiles destined for Earle are loaded from other barges. The barges containing the offloaded missiles are towed by commercial tugs approximately 40 miles up the York River to NWS Yorktown. Once at Yorktown the missiles are removed from the barges and placed in storage magazines. The missiles that are requested for transfer to Earle are loaded onto barges and then towed to the awaiting AOE in Norfolk.

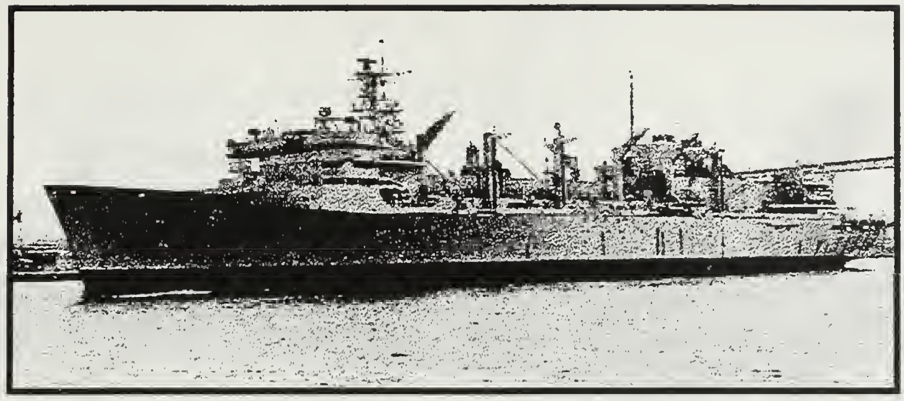

Figure 6. USS SUPPLY (AOE 6). [Ref. 10]

The fifth and final method utilizes U.S. Army LSVs (Logistic Support Vessels - see Figure 7). These vessels are charged with moving ordnance for all services in time of war. However, the Army personnel have never been trained in moving break-bulk ordnance. In partnership with the Navy, the three vessels stationed at Ft. Eustis in Newport News, Virginia have been used in four Joint Ordnance Movement Exercises (JORD MOVEX) to date. There are two purposes of these exercises. One is to train the Army stevedores in onloading and offloading naval ordnance; the second is to move Naval ordnance. The only costs to the Navy when using the LSVs is for fuel and handling the missiles. Currently, the Navy is trying to schedule two JORD MOVEX's per year.

Figure 7. U.S. Army LSV. [Ref. 11]

The offload process has to be modified if the LSVs are to be used on a regular basis to transport missiles between Earle and Yorktown. Since the LSVs are available at most twice a year, the unserviceable missiles offloaded at Earle may have to be placed into long term storage magazines awaiting the next LSV exercise. As part of the JORD MOVEX, the LSV onloads any serviceable missiles at Yorktown that need to be transferred to Earle, transits the approximate 360 nautical miles to Earle and offloads the missiles. The LSV then onloads any unserviceable missiles bound for Yorktown at Earle and then transports them to Yorktown. If the JORD MOVEX's are scheduled in conjunction with the major offloads at Earle (either an AOE returning from deployment or the non-deploying AOE offloading the carriers ordnance), then the amount of time the unserviceable missiles are stored at Earle will be minimized.

D. COSTS ASSOCIATED WITH TRANSPORTING ORDNANCE

There are several costs incurred when transporting ordnance between NWS Earle and NWS Yorktown. Some examples are manpower utilized during the ordnance handling evolutions; inspections of trucks and rail cars prior to departure from one weapons station and upon arrival at another one; blocking and bracing, which refers to the securing of the ordnance on the truck or container for the trip; the holding cost at a weapons station; and the cost of transportation itself, i.e., the truck, rail car, LSV, or AOE.

These and any other additional costs are covered under two DoD funds. The first is the Service Worldwide Transportation (SWT) fund. The fund is used when commercial assets are utilized to transport munitions and thus would pay for the actual truck or rail car, and the fuel for the LSV. The handling personnel and inspectors are paid a standardized wage which comes from the Navy's Receipt, Securing, Storage, and Inspection (RSS&I) budget. The cost of holding ordnance in magazines also comes from this fund. The RSS&I budget is extremely small and currently used to its maximum.

III. COST ELEMENTS

This chapter is concerned with the costs associated with transporting missiles, especially those costs which differ between the various transportation methods. There are three different groups of cost elements discussed in this chapter. The cost elements which are not affected by modal choice, and hence not included in the calculations, are discussed first. The cost elements which vary with the number of missiles being transported are discussed second. Finally, the cost elements that vary with the number of vehicles are discussed last. The final section of this chapter develops and discusses the equations utilized during the analysis. These equations are used to calculate the total cost to transport a given number of missiles, via a given transportation method. Cost curves are then generated for each transportation type over a range of missiles and then the curves are compared graphically and numerically to determine the most cost effective method of transportation.

A. OMITTED COSTS

There are several aspects of each transportation process that are omitted from the analysis. The reason for the omissions is that these costs occur in each process, with the same value, and if included, they would just inflate all the costs generated by the equations at the same rate and add no information as to what the true total variable cost is. Thus, these cost elements would have no impact on mode choice. The first of these cost elements is the cost incurred when missiles are offloaded at Earle from ships returning from deployment. These missiles are offloaded at the same cost no matter which type of transportation method is utilized. The second cost element is incurred when ships preparing for deployment onload missiles at Earle. Again, the costs are the same no matter the transportation method. The third cost element is the cost to store missiles at the weapons stations. This is the same for both weapons stations, therefore adding no new information to the cost equations. Finally, the fourth cost element that is the same for all the six transportation processes is the cost to maintain and repair missiles at Yorktown.

B. COSTS VARYING WITH THE NUMBER OF MISSILES

This section is concerned with the cost elements that vary with the number of missiles that require transport in a given movement. The two cost elements that vary with the number of missiles are the loading cost and the unloading cost. The loading cost is the cost incurred when one missile is loaded onto a transportation vehicle, i.e. flatbed, container, boxcar, LSV, or AOE. The unloading cost is incurred when one missile is unloaded from a transportation vehicle. Each of these costs are multiplied by the number of missiles requiring transport and cause the total cost of transportation to increase as the number of missiles increases.

The load and unload costs are generated by multiplying a standard hourly wage by the number of man-hours needed to complete the task. Table 1 shows the man-hours needed to perform the different tasks at Earle and Yorktown. These man-hours are associated with the four commercial transportation methods only. The man-hours needed to load and unload a missile traveling on a DoD transportation method are not listed because the data associated with the DoD methods was received already in the form of cost per missile to load or unload a missile.

Missile	Load at Earle	Unload at Earle	Load at Yorktown	Unload at Yorktown
Harpon	7.83	3.58	11.45	16.55
Phoenix	2.05	0.94	3	4.34
Sidewinder	0.42	0.19	0.62	0.89
Sparrow	0.93	0.42	1.36	1.96

Table 1. Man-hours to load or unload missiles (for commercial methods only). [Ref. 12]

C. COSTS VARYING WITH THE NUMBER OF VEHICLES

This section discusses the cost elements that vary as the number of vehicles required to transport missiles changes. The cost elements are transport rates and inspection costs.

In the commercial sector transport rates for a given transportation method can vary depending on the distance, weight of the freight to be transported, or the amount of freight to be transported. In this analysis the transport rates (or rental rates) are fixed and will not vary because the distance between NWS Earle and NWS Yorktown for each of the commercial transportation methods is below minimum distances for the commercial carriers, and the weight of commercial vehicles, fully loaded with missiles, does not exceed the minimum weights published by the commercial carriers. The transport rates for the two DoD transportation methods (LSV and AOE) are the cost for fuel needed for a one way trip, either from Earle to Yorktown or from Yorktown to Earle.

The inspection costs are costs incurred when vehicles are either loaded or unloaded. The inspection for a vehicle that is being loaded is a visual inspection that checks the securing of the missiles prior to transport. The unload inspection occurs when a vehicle arrives at a weapons station and is also visual. The purpose of the unload inspection is to ensure that there has been no shifting of the missiles while in transit that may cause a hazardous situation during the offload of the vehicle. The total cost equations for the DoD transportation methods (LSV and AOE) do not have a separate inspection term because the inspection costs are incorporated into the load and unload costs discussed in the previous section. In part, this is because the cost data associated with the DoD methods was received in a different format than the cost data associated with the commercial methods.

An example of the data associated with the transportation rates and inspection costs are given in Table 2. Column B shows that the transportation rate generally increases as the size of the vehicle increases. When these values are divided by the vehicle capacity (column C), we see that the average cost per missile, for a full load (column D), generally decreases as the vehicle capacity increases.

Method (A)	Cost per vehicle * (B)	Vehicle capacity (missiles) (C)	Cost per missile with full vehicles (D)	Inspection cost per missile with full load (E)	Total cost per missile with full load, (D + E)
Truck (Container)	$ 1,401.00	24	$ 58.38	$ 3.86	$ 62.23
Truck (Flatbed)	$ 1,427.00	72	$ 19.82	$ 1.29	$ 21.11
Rail (Boxcar)	$ 2,830.00	90	$ 31.44	$ 1.03	$ 32.47
Rail (Container)	$ 2,830.00	96	$ 29.48	$ 0.96	$ 30.44
AOE	$ 26,506.12	4500 **	$ 5.89		$ 5.89
LSV	$ 11,500.00	4500 **	$ 2.56		$ 2.56

* These values are not dependent on missile type.
** These values are just estimates and cause the cost per missile to be suspect. Also, the cost per missile is unrealistic because the vessels have such large capacities that they would never be filled with a full load.

Table 2. Transportation Rate and Inspection costs associated with transporting Sparrow missiles.

The inspection cost per vehicle is $92.60 for all commercial vehicle types. This cost incorporates both the load and unload inspection costs and is based on the man-hours required to conduct the inspections. The man-hours needed to conduct a load inspection are 0.5, and the man-hours needed to conduct a unload inspection are 0.33. By adding the man-hours together and then multiplying by the standard hourly wage ($111.57/man-hour) the total inspection cost is calculated. The inspection cost per missile with full loads is presented in column E. We see that this cost generally decreases as the vehicle size increases. The final column shows the total cost per missile (transportation and inspection) with full loads.

D. TOTAL COST EQUATIONS

Each method and missile combination has two equations utilized to calculate the total transportation cost, one for transporting the missiles from NWS Earle to NWS Yorktown (called SOUTH equations) and one for transporting the missiles from NWS Yorktown to NWS Earle (called NORTH equations). In general terms, the total cost (TC) equations per movement are of the form:

Total Cost = (missiles*$/missile) + (vehicles*$/vehicle).

The first part of the equation is made up of the costs that vary with the number of missiles and the second part is made up of the costs that vary with the number of vehicles.

The following subsections describe the generation of the SOUTH and NORTH equations. Even though the equations for each transportation method have the same general format, the generation and description of the equations is broken into two sections, one for commercial methods and another for DoD methods. The reason for this split is because of the difference in format of the cost data between the commercial and DoD methods.

1. Cost Equations For Commercial Transportation Methods

The equations that are used to calculate the total cost to transport the missiles south and north are of the same format for all the commercial transportation methods. The formulation of the equations are as follows:

Index

i - missile type
j - commercial transportation type
k - load/unload location (Earle, Yktn)

Data

CAP_{ij} - capacity of missile i on trans type j.
WAGE - standardized hourly rate for weapon station personnel.
LD_HRS_{ijk} - man-hours required to load one missile type i onto trans type j at location k.
$UNLD\_HRS_{ijk}$ - man-hours required to unload one missile type i from trans type j at location k.
LD_INSP_{ijk} - man-hours to inspect trans type j, loaded with missile type i, at location k prior to departure.
$UNLD\_INSP_{ijk}$ - man-hours to inspect trans type j, loaded with missile type i, at location k prior to offload.
$RATE_j$ - transportation rate for transportation type j.

Variables

x_{ij} - number of missile type i on transportation type j.

Equations

$$TCSTH_{ij} = (WAGE*LD\_HRS_{ij,Earle})*x_{ij} + (WAGE*UNLD\_HRS_{ij,Yktn})*x_{ij} + [RATE + (WAGE*LD\_INSP_{ij,Earle}) + (WAGE*UNLD\_INSP_{ij,Yktn})] * ROUNDUP(x_{ij}/CAP_{ij}).$$

$$TCNTH_{ij} = (WAGE*LD\_HRS_{ij,Yktn})*x_{ij} + (WAGE*UNLD\_HRS_{ij,Earle})*x_{ij} + [RATE + (WAGE*LD\_INSP_{ij,Yktn}) + (WAGE*UNLD\_INSP_{ij,Earle})] * ROUNDUP(x_{ij}/CAP_{ij}).$$

The constant WAGE used in the equations is a standardized hourly wage of $111.57 for one ordnance handler at either weapons station. LD_HRS_{ijk} gives the man-hours needed to load a missile of type i onto transportation type j at location k. When LD_HRS_{ijk} is multiplied with WAGE the resulting calculation gives the cost to load one missile type i on transportation type j. $UNLD\_HRS_{ijk}$ gives the man-hours required to unload a missile of type i off transportation type j at location k, and when multiplied with WAGE results in the cost to unload one missile type i, from transportation type j, at location k. This makes up the second portion of the equations.

The third portion calculates the costs that vary with the number of vehicles. The transportation rate and inspection cost are added together and then multiplied by the number of vehicles needed to transport the given missiles. The ROUNDUP function utilized in this portion of the total cost equations allows for the automatic increase in the number of assets needed for each type of method. This function generates a positive integer which gives the number of vehicles needed. For example, assume nine Harpoons need to be transported via commercial trucks with 48-foot flatbeds. Since the capacity of a single flatbed is eight Harpoons, ROUNDUP(9/8) = 2, which means that two trucks and flatbeds are needed. This function ensures the correct rental cost for the trucks and flatbeds is calculated.

The results of the total cost equations gives the cost to transport any number of missiles (in dollars), either north or south.

To demonstrate these equations the total cost to transport fifteen Harpoons, on commercial trucks with 48-foot flatbeds, from NWS Earle to NWS Yorktown is calculated. The applicable data for this missile/method/direction combination is shown in Table 3.

WAGE	111.57 *	$/manhr
$LOAD\_HRS_{Harpoon,Fltbed,Earle}$	7.83 *	manhr/missile
$UNLOAD\_HRS_{Harpoon,Fltbd,Yktn}$	16.55 *	manhr/missile
$LOAD\_INSP_{Harpoon,Fltbd,Earle}$	0.5 *	manhr/fltbd
$UNLOAD\_INSP_{Harpoon,Fltbd,Yktn}$	0.33 *	manhr/fltbd
$CAP_{Harpoon,Fltbd}$	8 **	missiles/flatbd
RATE	1427.00 ***	$/flatbd
* Ref. 12, ** Ref. 13, *** Ref. 14		

Table 3. Data associated with transporting Harpoon missiles from Earle to Yorktown utilizing flatbed trucks.

By applying these numbers to the SOUTH equation the cost to transport the Harpoons south is $43,840.36.

2. Cost Equations For DoD Transportation Methods

This section discusses the equations used to calculate the cost to transport a given number of missiles between Earle and Yorktown via the DoD transportation methods (LSV and AOE). The main difference between these equations and the equations from the previous section is that the LD_INSP and UNLD_INSP terms are not explicitely used in the equations. As stated earlier, these costs are imbedded in the cost to load and unload missiles to and from the DoD assets.

The formulation of the equations generated for the DoD transportation methods are similar to the equations for the commercial methods. The equations are listed below. All indices, data, and variables not explicitely listed below (and used in the equations) are the same as listed in the commercial formulation in the previous section.

Data

$LOAD_{ijk}$ - cost to load one missile type i on transportation type j at location k.

$UNLOAD_{ijk}$ - cost to unload one missile of type i from transportation type j at location k.

Equations

$$TCSTH_{i,LSV} = LOAD_{ij,Earle}*x_{ij} + UNLOAD_{ij,Yktn}*x_{ij} + RATE_j*ROUNDUP(x_{ij}/CAP_{ij}).$$

$$TCNTH_{i,LSV} = LOAD_{ij,Yktn}*x_{ij} + UNLOAD_{ij,Earle}*x_{ij} + RATE_j*ROUNDUP(x_{ij}/CAP_{ij}).$$

$$TCSTH_{i,AOE} = LOAD_{ij,Earle}*x_{ij} + UNLOAD_{ij,Anchge} + RATE_j*ROUNDUP(x_{ij}/CAP_{ij}).$$

$$TCNTH_{i,AOE} = LOAD_{ij,Anchge}*x_{ij} + UNLOAD_{ij,Earle}*x_{ij} + RATE_j*ROUNDUP(x_{ij}/CAP_{ij}).$$

To give the reader a comparison of the costs for transporting a given number of each type of missile being transported by each type of transportation method (both commercial and DoD), Tables 4 and 5 show the cost to transport one missile via each of the transportation types. The data used to calculate these costs are given in Appendix A.

	Harpoon	Phoenix	Sidewinder	Sparrow
48-foot Flatbed	$ 4,239.68	$ 2,232.54	$ 1,665.76	$ 1,842.04
Truck with container	$ 4,213.68	$ 2,206.54	$ 1,639.76	$ 1,816.04
Rail with container	$ 5,642.68	$ 3,635.54	$ 3,068.76	$ 3,245.04
Rail Boxcar	$ 5,642.68	$ 3,635.54	$ 3,068.76	$ 3,245.04
LSV	$ 13,610.52	$ 12,523.68	$11,726.01	$ 12,138.14
AOE	$ 36,674.18	$ 34,108.10	$32,224.74	$ 33,197.81

Table 4. Cost to transport one missile south.

	Harpoon	Phoenix	Sidewinder	Sparrow
48-foot Flatbed	$ 3,196.50	$ 1,959.19	$ 1,609.97	$ 1,718.20
Truck with container	$ 3,170.50	$ 1,933.19	$ 1,583.97	$ 1,696.66
Rail with container	$ 4,599.50	$ 3,362.19	$ 3,019.97	$ 3,121.20
Rail Boxcar	$ 4,599.50	$ 3,362.19	$ 3,019.97	$ 3,121.20
LSV	$ 13,610.52	$ 12,523.68	$11,726.01	$ 12,138.14
AOE	$ 33,883.95	$ 32,754.72	$31,925.95	$ 32,354.14

Table 5. Cost to transport one missile north.

E. COST CURVE GENERATION

The generation of the missile cost curves is the next step in the analysis. These curves are generated by using the total cost equations from the previous sections to calculate the cost to transport any number of missiles, from one missile up to a designated maximum number. The designated maximum number of missiles is based on the number of each missile type in the Navy's east coast inventory. Table 6 shows the range of missiles used in the analysis for each type of missile. These numbers do not add up to the exact number of missiles in the east coast inventory, but they are a close approximation.

Missile	Cost Curve Range
Harpoon	1 - 70
Phoenix	1 - 120
Sidewinder	1 - 950
Sparrow	1 - 380

Table 6. Cost Curve Ranges.

To generate the curves a spreadsheet program is utilized. The layout of the spreadsheet is provided in Appendix B. Each missile type is treated separately, and the cost curves for all six transportation methods are generated for both the transporting of missiles from NWS Earle to NWS Yorktown and NWS Yorktown to NWS Earle. There are forty-eight cost curves generated (twelve per missile type).

IV. ANALYSIS RESULTS

This chapter discusses the results of the analysis. For each missile type a decision policy is generated. These policies (eight in all) will ensure the most cost effective method is utilized, given the number of missiles needing transport.

After the cost curves for each transportation method are generated for a given missile type (going in one direction), the curves are compared (graphically and numerically) to determine if any breakpoints exist within the range of missiles being analyzed. A breakpoint occurs when two cost curves intersect. For example, a breakpoint is seen to occur when 41 Sidewinders need to be transported from Yorktown to Earle. The two methods involved at this breakpoint are trucks with containers and trucks with flatbeds. To the left of the breakpoint a truck with containers is the least expensive method, and above the breakpoint a truck with a flatbed is the least expensive method. Since many of the cost curves (for a given missile type and direction) are close together, comparing them graphically may only give an approximate range of missiles where a breakpoint is located. To determine the exact location of the breakpoint, each point within the range must be numerically compared for each transportation method around the intersection area. Once all breakpoints are determined for a given missile type and transportation method, the decision policy is generated. The following sections detail the comparisons and resulting decision policies. The axes in the graphs shown in the following sections have been adjusted to give the viewer the greatest detail possible so that breakpoints are viewable.

A. HARPOON

1. NWS Earle to NWS Yorktown

The results of the comparison of the six cost curves associated with transporting Harpoon missiles from NWS Earle to NWS Yorktown show that five of the six methods can feasibly be used in the decision policy. The graphs of the six curves and their relationships with each other are shown in Figure 8.

Observing Figure 8 it can be seen that the method of using an AOE as a shuttle ship is not economically feasible; the methods of Truck (Flatbed), Truck (Container), Rail

(Container), and Rail (Boxcar) are reasonably close together, and the best method to use can not be easily determined. By comparing the remaining five methods numerically the best policy is then determined. As a result

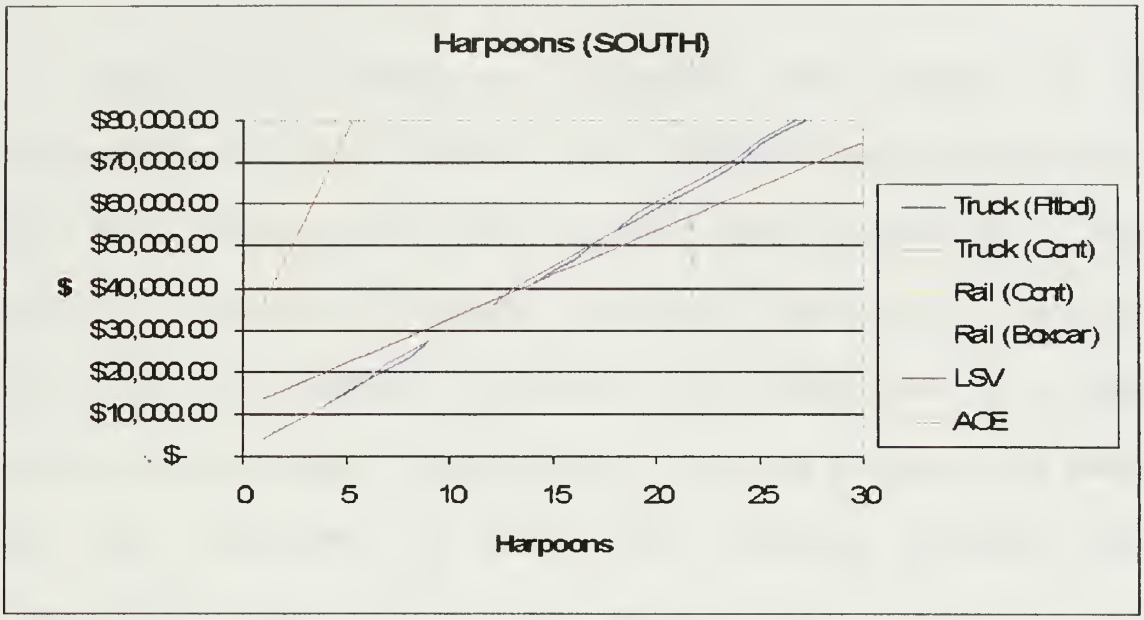

Figure 8. HARPOON (South Cost Curves)[2].

of this comparison the decision policy to use to transport Harpoons from Earle to Yorktown is as follows:

- Use trucks with containers for one to six Harpoons.

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[2] The x-axis range has been adjusted for this graph (and all the following graphs) to show the maximum detail. The actual range used in the analysis is shown in Table 6.

- Use trucks with flatbeds for seven to eight Harpoons.
- Use either rail with containers or rail with boxcars for nine to 14 Harpoons.
- Use LSV for any number of Harpoons greater then 14.
- Use AOE only as a last resort if none of the above methods are available.

When the number of missiles that needs to be transported south is between nine and thirteen either of the two rail options will be the most cost effective. This result is because of several factors. The first is that the rent cost for either a railcar with containers or a rail boxcar is the same. Because the distance between NWS Earle and NWS Yorktown is below the minimum distance for commercial rail rates, and because the weight of the missiles does not exceed 100,000 lbs., the rental rate for both methods is given the same value. The second factor that causes the curves to be equal is that the capacity for both of the methods is 24 Harpoons. Since the cost to load and unload one harpoon is the same for both methods, handling the same number of missiles leads to the same cost. Because of these two factors the numerical results for the

two methods are equal. This result also holds true for transporting Harpoons north from NWS Yorktown to NWS Earle.

The numerical findings for the cost curves associated with transporting Harpoons south are provided in Appendix C.

2. NWS Yorktown to NWS Earle

The results of the comparison of the six cost curves associated with transporting Harpoon missiles from NWS Yorktown to NWS Earle show that only four of the methods are used in the decision policy. The graphs of the six curves and their relationships with each other are shown in Figure 9.

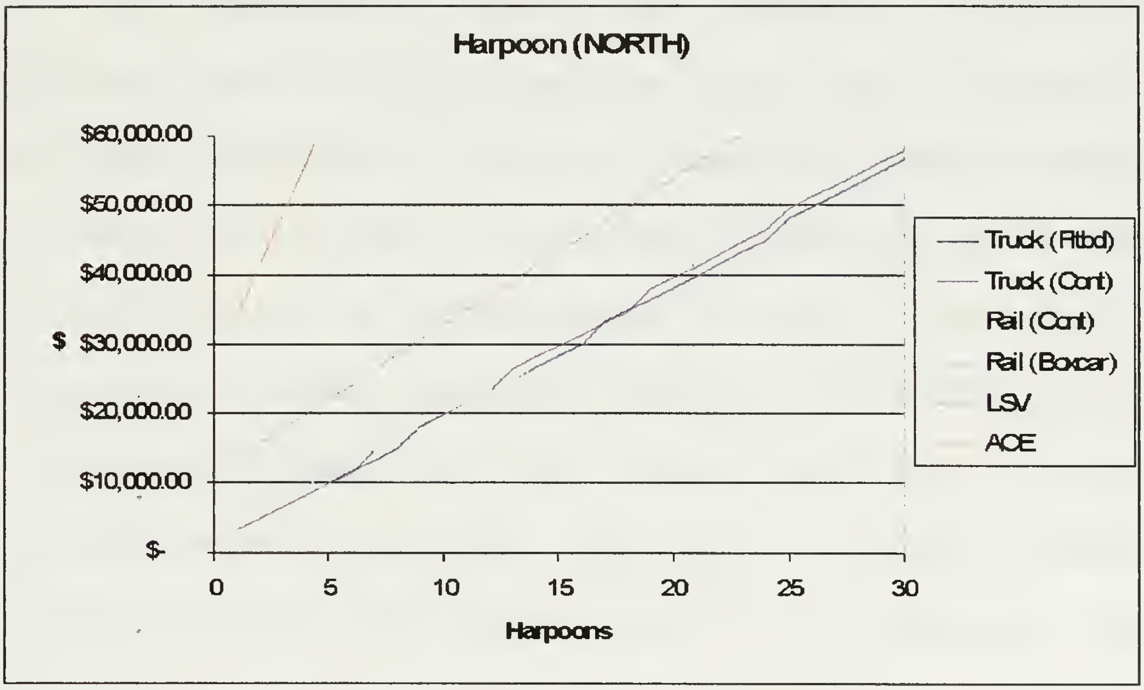

Figure 9. HARPOON (NORTH Cost Curves).

Observing the graph shows that the LSV and AOE cost curves are always above the other four methods and thus are not included in this decision policy. The decision policy is:

- Use trucks with containers for one to six Harpoons.
- Use trucks with flatbeds for seven to eight Harpoons.
- Use either rail with containers or boxcars for any number of Harpoon missiles greater then eight.
- Use LSV only if the above methods four methods are not available.
- Use AOE only as a last resort.

The difference between the decision policies for Harpoons going north and Harpoons going south is caused by the high difference in man-hours required to handle Harpoons at Earle and Yorktown. In the case of Harpoons going south the combination of the man-hours to load at Earle and to unload at Yorktown causes the slopes of the curves for the commercial methods to be high enough so that they intersect with the curve for the LSV. The costs to transport Harpoons north for trucks with flatbeds, trucks with containers, rail

with containers, and rail with boxcars are all approximately sixty percent less than transporting them south.

B. PHOENIX

1. NWS Earle to NWS Yorktown

The results of the comparison of the six cost curves associated with transporting Phoenix missiles from NWS Earle to NWS Yorktown show that four of the six methods are used in the decision policy. The four methods are trucks with flatbeds, trucks with containers, rail with containers, and rail with boxcars. The graphs of the six curves and their relationships with each other are shown in Figure 10.

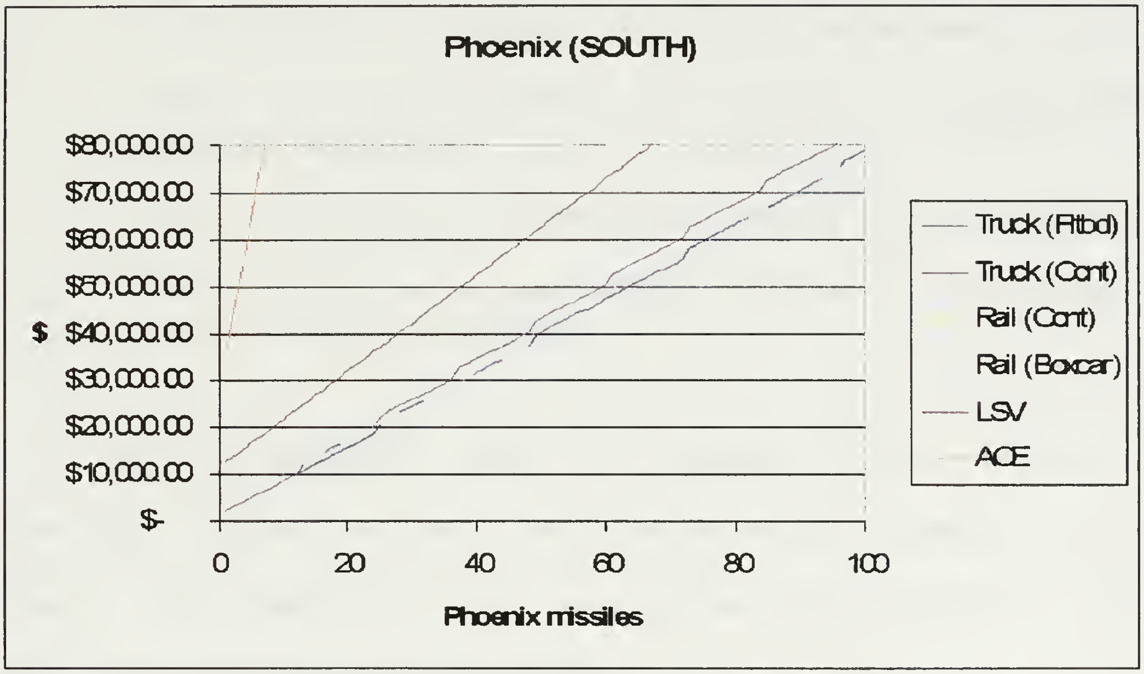

Figure 10. PHOENIX (SOUTH Cost Curves).

Figure 10 shows that the AOE and LSV methods will not be part of the decision policy. As a result of the comparison of the numerical values the decision policy to use to transport Phoenix missiles from Earle to Yorktown is as follows:

- Use trucks with containers for one to 12 Phoenix missiles.
- Use trucks with flatbeds for 13 to 24 Phoenix missiles.
- Use either rail with containers or rail with boxcars for 25 through 48 Phoenix missiles.
- Use truck with flatbeds to transport 49 through 72 Phoenix missiles.
- Use either rail with containers or rail with boxcars to transport 73 through 96 Phoenix missiles.
- Use trucks with flatbeds to transport 97 through 120 Phoenix missiles.
- Use LSV only if no commercial assets are available.
- Use AOE only as a last resort if none of the above methods are available.

As with Harpoons, when the decision policy states to use rail, either rail with containers or rail boxcars can be used. The reason for this is because the rental cost and cost per missile for both methods is the same.

2. NWS Yorktown to NWS Earle

The results from comparing the cost curves associated with transporting Phoenix missiles from Yorktown to Earle shows that trucks with flatbeds, trucks with containers, rail with containers, and rail boxcars are the only methods that are feasible. Figure 11. shows this graphically.

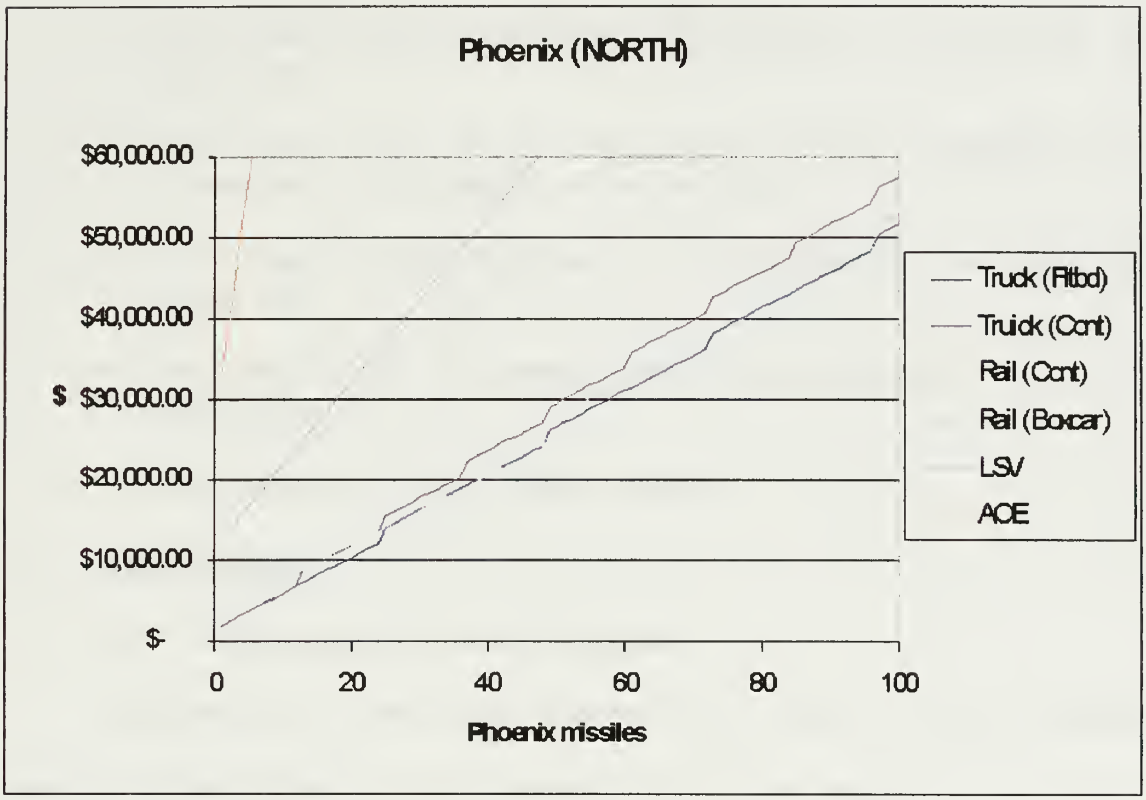

Figure 11. Phoenix (NORTH Cost Curves).

The comparison of the cost curves for transporting Phoenix missiles north shows that the LSV and AOE methods

are too costly to be effective. The decision policy for moving Phoenix's north are listed as follows:

- Use trucks with containers to move one through 12 Phoenix missiles.
- Use trucks with flatbeds to transport 13 through 24 missiles.
- Use either rail with containers or rail boxcars to transport 25 through 48 missiles.
- Use trucks with flatbeds to transport 49 through 72 missiles.
- Use either rail with containers or rail boxcars to transport 73 through 96 missiles.
- Use trucks with flatbeds to transport 97 through 120 missiles.
- Use LSVs only if commercial assets are not available.
- Use AOEs only as a last resort.

C. SIDEWINDER

1. NWS Earle to NWS Yorktown

Analysis of the cost curves for each of the methods moving Sidewinders south reveals that the decision policy is made up of only the truck with containers, truck with flatbeds, and rail boxcars methods. See Figure 12.

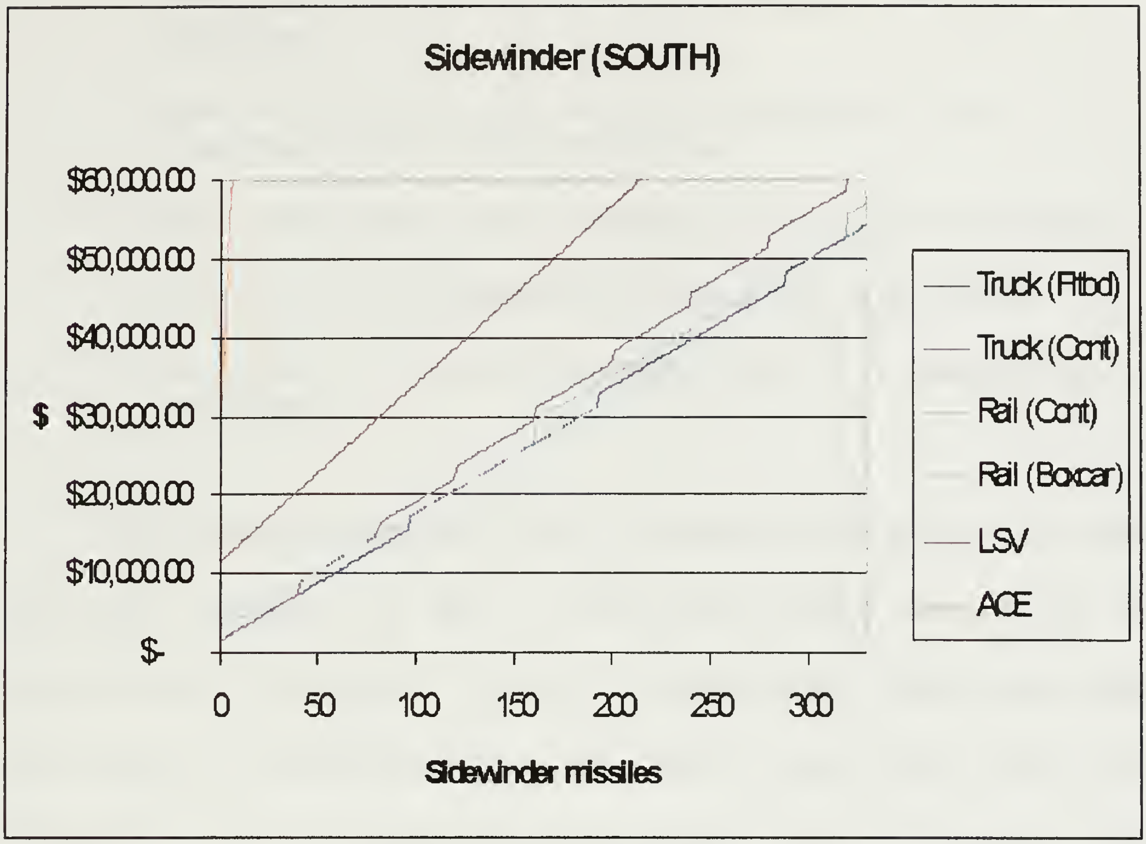

Figure 12. SIDEWINDER (SOUTH Cost Curves).

The decision policy for transporting Sidewinders south is as follows:

- Use trucks with containers to transport one to 40 Sidewinders.
- Use trucks with flatcars to transport 41 to 96 Sidewinders.
- Use rail with containers or rail boxcars to transport 97 to 160 missiles.

- Use trucks with flatcars to transport 161 to 288 missiles.
- Use rail with containers or rail boxcars to transport 289 to 320 missiles.
- Use rail boxcars to transport 321 to 950 missiles.
- Use LSV if no commercial assets are available.
- Use AOEs if there is no other way to transport the missiles.

The jumping back and forth between trucks with flatbeds and rail boxcars is due to multiple places where the two cost curves intersect. These intersections take place when the method associated with the lower curve goes over it's capacity ,i.e., a new boxcar is needed, which causes a jump in the curve due to another rental and inspection cost being added into the cost.

2. NWS Yorktown to NWS Earle

The methods that prove to be the most cost effective to transport Sidewinders north are the same ones used to transport them south. The relationships between the cost curves can be seen in Figure 13.

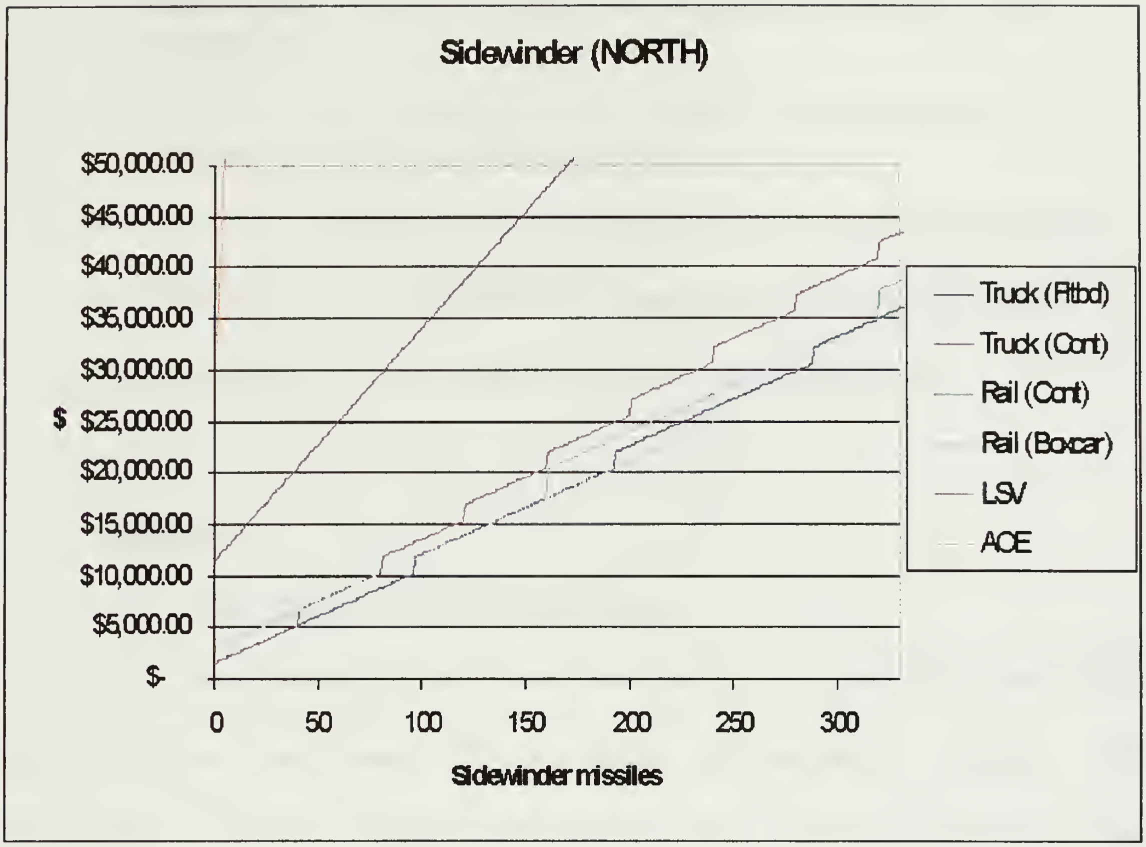

Figure 13. SIDEWINDER (NORTH Cost Curve).

The decision policy for transporting Sidewinders from Yorktown to Earle is:

- Use truck with containers to transport one to 40 Sidewinders.
- Use truck with flatbeds to transport 41 to 96 missiles.
- Use rail with containers or rail boxcars to transport 97 to 160 missiles.
- Use rail boxcars to transport 161 to 240 missiles.

- Use truck with flatbeds to transport 241 to 288 missiles.
- Use rail with containers or rail boxcars to transport 289 to 320 missiles.
- Use rail boxcars to transport 321 to 950 missiles.
- Use LSV if no commercial methods are available.
- Use AOE's if no other method is available.

D. SPARROW

1. NWS Earle to NWS Yorktown

The conclusion from the analysis of the Sparrow SOUTH cost curves is that truck with containers, truck with flatbeds, and rail with containers are the methods utilized in the decision policy. The policy is:

- Use trucks with containers to transport one to 24 Sparrows.
- Use trucks with flatbeds to transport 25 to 72 Sparrows.
- Use rail with containers or rail boxcars to transport 73 to 96 Sparrows.
- Use trucks with flatbeds to transport 97 to 380 Sparrows.
- Use LSV only if no commercial assets are available.
- Use AOEs only as a last resort.

The graph of the cost curves generated for Sparrows being transported south is shown in Figure 14.

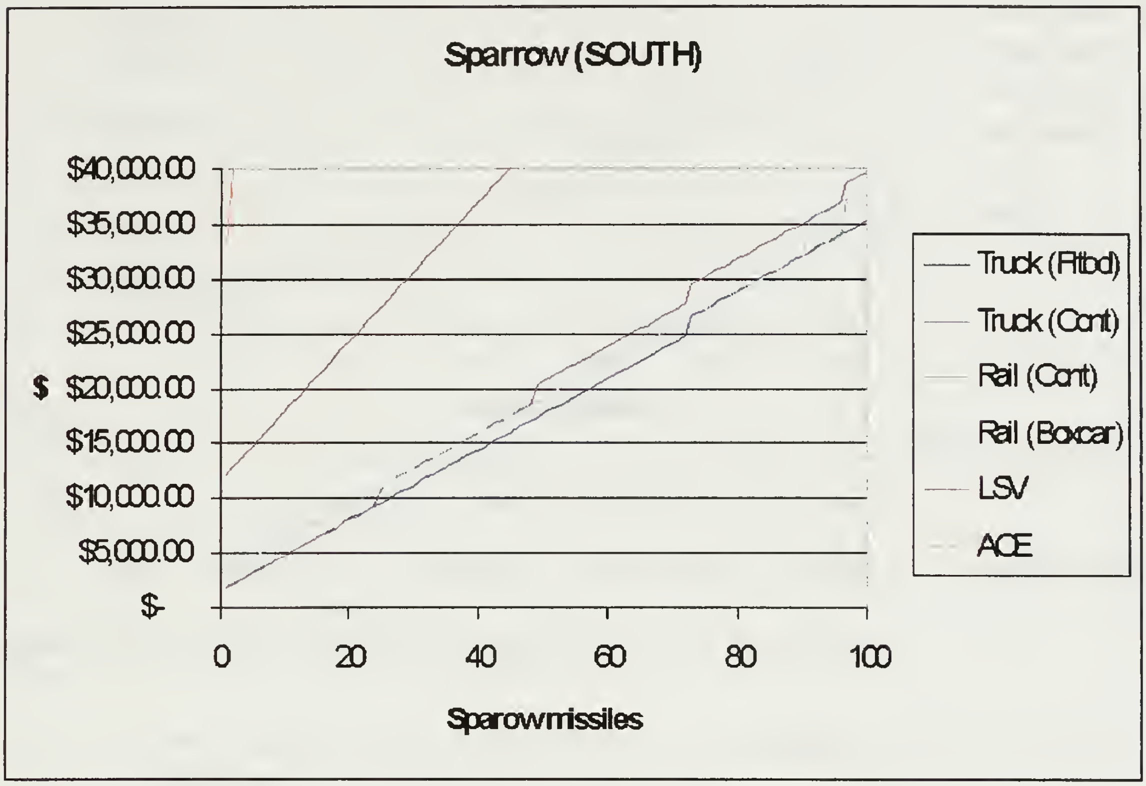

Figure 14. SPARROW (SOUTH Cost Curves).

2. NWS Yorktown to NWS Earle

The methods that are used in the decision policy when transporting Sparrow missiles north are trucks with containers, trucks with flatbeds, and rail with containers. The graph of the six cost curves are given in Figure 15.

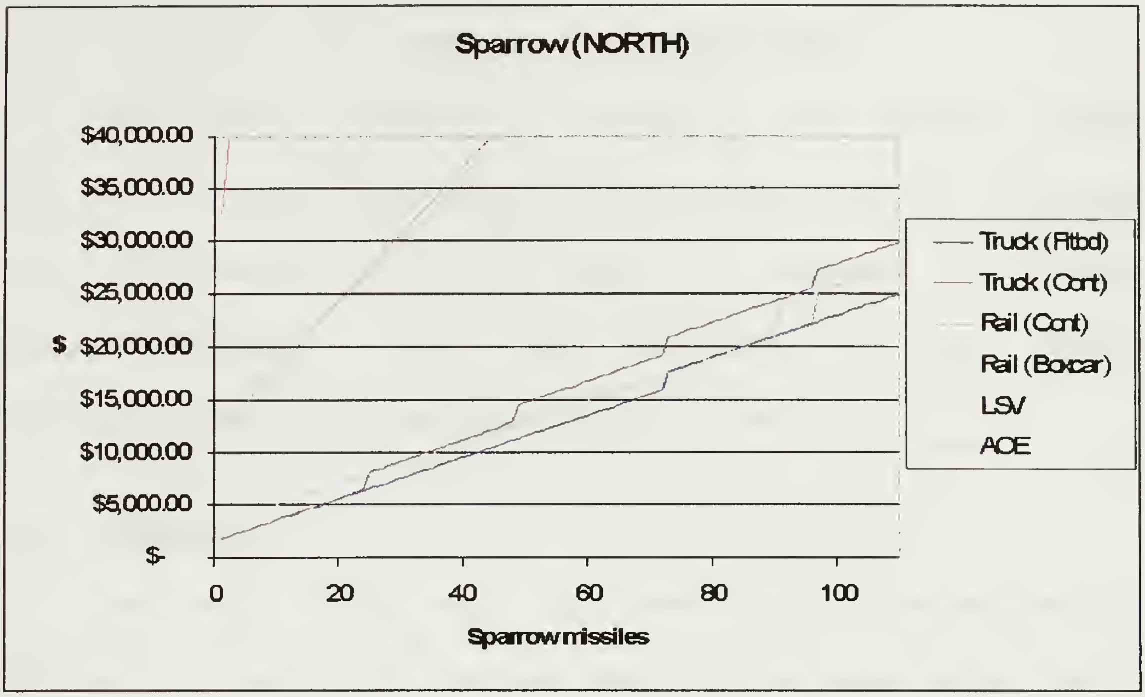

Figure 15. SPARROW (NORTH Cost Curves).

The decision policy associated with transporting Sparrows from Yorktown to Earle is as follows:

- Use trucks with containers to transport one to five Sparrows.
- Use trucks with flatbeds to transport six to 72 missiles.
- Use rail with containers or rail boxcars to transport 73 to 96 missiles.
- Use trucks with flatbeds to transport 97 to 380 Sparrows.
- Use LSV if no commercial assets are available.
- Use AOEs only as a last resort when no other methods of transportation are available.

V. SUMMARY AND CONCLUSIONS

This chapter provides a summary of the original problem and the analysis conducted. The second section discusses the conclusions of the author's research and makes recommendations. The final section of this chapter discusses follow-on research that can be done.

A. SUMMARY

The Navy, along with the rest of the Department of Defense, is having to perform many of the same tasks that it has historically performed but on a tighter budget that continues to shrink. Because of this everyone is having to learn to utilize all available funds in the most productive manner. This problem has led CINCLANTFLT to ask the question of which is the most cost effective method of transporting air-launched missiles between NWS Earle and NWS Yorktown. The six possible methods of transporting these missiles, commercial trucks with 48-foot flatbeds, commercial trucks with 20-foot End-opening containers, commercial rail flatcars with 20-foot containers, commercial rail boxcars, U.S. Navy ordnance ships, and U.S. Army watercraft, have been analyzed and compared. The results of this analysis are in the form of decision policies that if followed by the ordnance manager ensure that the most cost effective method of transportation is being used for the given number and type of missiles that need to be transported. If a mix of missile types are being shipped, greater efficiencies can be achieved by loading multiple missile types on the same vehicle, thus reducing the total cost.

B. CONCLUSIONS

1. Commercial assets are the most cost effective

The two military options are almost always quite inefficient relative to the commercial alternatives. The AOE option is always inferior to commercial alternatives, and in only one context is the LSV option found to be superior to the commercial alternatives.

Only one of the graphs of cost curves generated during the analysis shows that LSVs should be employed to transport missiles. That graph is for transporting Harpoon missiles from NWS Earle to NWS Yorktown. All the other graphs show that the LSV option will cost more than the commercial assets for any number of missiles. The phenomenon seen with Harpoon missiles going south is caused because the cost per missile to load and offload Harpoons from and to commercial assets is greater than to load or offload them via LSV. All of the graphs show that the AOE transportation method should only be utilized as a last resort because of the high costs incurred when loading and offloading at anchorage.

2. LSV's should generally not be utilized as a pure cost saving method of transportation

While researching the use of LSV's the author was told that there had been a substantial savings by using LSVs to transport ordnance over commercial trucks. This savings was in money that would have come from the SWT fund and did not take into account the cost to the RSS&I fund, which covers the ordnance handling at the weapons stations. This analysis shows that even though money is saved from the SWT fund there is a greatly increased burden on the RSS&I fund, which is pushed to it's limits already. Therefore, utilizing LSVs purely on a cost saving basis is not the best way to do business. Although, when the other benefits of using this asset are weighed into the decision process, i.e., training for both Army and Navy units, then the overall benefits from using this asset may overcome the additional costs to the RSS&I budget.

3. AOEs should not be utilized as missile transportation methods

In all the analysis cases, the option of AOE was the most cost prohibitive because of two reasons. The first was that the rental cost (one way transit cost) was so much higher than the other methods; the second was due to the load and unload cost per missile being greater than the other methods. These two factors caused the cost curves for AOEs to intercept the y-axis at a higher point and to have higher slopes than the other methods, thus preventing the AOE cost curves from crossing the other cost curves no matter how many missiles were to be transported. This result would be the same for using an AE since the rental cost for an AE is approximately the same as an AOE. Also, the load and unload costs would be the same since the AE would have to load and unload the missiles at anchorage.

C. AREAS OF FURTHER STUDY

1. Use of Side-opening Containers

The trend within the DoD is to use 20-foot side-opening containers when transporting ordnance. The major advantage these containers have over the end-opening ones is ease of access. Since the whole side of the container can be opened, positioning of the ordnance is much easier, thus reducing the time needed to load and unload the containers. No capacity data was available for the missiles discussed in this thesis so this option was not analyzed. A comparison of this method with the other possible methods could be accomplished after the load capacities were determined.

2. Mixed Loads

The analysis done in this thesis focused on each type of missile separately. Further analysis could take place in determining the best method of transportation given that multiple types of missiles could be carried on a given method at the same time, i.e., both Sparrows and Sidewinders on a 48-foot flatbed truck. Theoretically, some efficiencies could be incurred with mixed loads.

APPENDIX A - DATA USED IN ANALYSIS

The tables listed below show the data utilized during the analysis. They show the transportation rates associated with the different transportation methods, and the load and unload costs associated with the weapons stations.

Truck (flatbed) *	$ 1,427.00
Truck (Container) *	$ 1,401.00
Rail (Container) *	$ 2,830.00
Rail (Boxcar) *	$ 2,830.00
LSV **	$ 11,500.00
AOE ***	$ 26,506.12
* Ref. 14, ** Ref. 16, *** Ref. 17	

Table 7. Transportation Rates.

	$/manhr	manhr/missile	$/missile
Harpoon	111.57	11.45	$ 1,277.48
Phoenix	111.57	3	$ 334.71
Sidewinder	111.57	0.62	$ 69.17
Sparrow	111.57	1.36	$ 151.74

Table 8. Loading at Yorktown (Commercial Methods). [Ref. 12]

	$/manhr	manhr/missile	$/missile
Harpoon	111.57	7.83	$ 873.59
Phoenix	111.57	2.05	$ 228.72
Sidewinder	111.57	0.42	$ 46.86
Sparrow	111.57	0.93	$ 103.76

Table 9. Loading at Earle (Commercial Methods). [Ref. 12]

	$/manhr	manhr/missile	$/missile
Harpoon	111.57	16.55	$ 1,846.48
Phoenix	111.57	4.34	$ 484.21
Sidewinder	111.57	0.89	$ 99.30
Sparrow	111.57	1.96	$ 218.68

Table 10. Unloading at Yorktown (Commercial Methods). [Ref. 12]

	$/manhr	manhr/missile	$/missile
Harpoon	111.57	3.58	$ 399.42
Phoenix	111.57	0.94	$ 104.88
Sidewinder	111.57	0.19	$ 21.20
Sparrow	111.57	0.42	$ 46.86

Table 11. Unloading at Earle (Commercial Methods). [Ref. 12]

	LOAD ($/missile)	UNLOAD($/missile)
Harpoon	$ 1,108.66	$ 1,001.86
Phoenix	$ 537.74	$ 485.94
Sidewinder	$ 118.72	$ 107.29
Sparrow	$ 335.22	$ 302.92

Table 12. LSV load/unload costs at Earle. [Ref. 15]

	LOAD ($/missile)	UNLOAD($/missile)
Harpoon	$ 1,108.66	$ 1,001.86
Phoenix	$ 537.74	$ 485.94
Sidewinder	$ 118.72	$ 107.29
Sparrow	$ 335.22	$ 302.92

Table 13. LSV laod/unload costs at Yorktown. [Ref. 15]

	LOAD ($/missile)	UNLOAD($/missile)
Harpoon	$ 1,108.66	$ 1,001.86
Phoenix	$ 537.74	$ 485.94
Sidewinder	$ 118.72	$ 107.29
Sparrow	$ 335.22	$ 302.92

Table 14. AOE load/unload costs at Earle. [Ref. 15]

	LOAD ($/missile)	UNLOAD($/missile)
Harpoon	$ 6,375.97	$ 9,059.40
Phoenix	$ 5,762.66	$ 7,064.24
Sidewinder	$ 5,312.54	$ 5,599.90
Sparrow	$ 5,545.10	$ 6,356.47

Table 15. AOE load/unload costs at Golf anchorage. [Ref. 15]

APPENDIX B - SPREADSHEET LAYOUT

The following is the spreadsheet layout used to generate the cost curves for transporting Harpoons from NWS Earle to NWS Yorktown. The layouts for the other seven missile/transportation method combinations are similar.

SOUTH EQUATION COSTS

METHODS	LOAD COST	UNLOAD COST	RENT	INSPECT COST	CAPACITY	COST/HARPOON
TRUCK WITH 48-FT FLATBED	$ 873.59	$ 1,846.48	$ 1,427.00	$ 92.60	8	$ 2,720.08
TRUCK WITH CONTAINER	$ 873.59	$ 1,846.48	$ 1,401.00	$ 92.60	6	$ 2,720.08
RAIL WITH 4 20-FT CONTAINER	$ 873.59	$ 1,846.48	$ 2,830.00	$ 92.60	24	$ 2,720.08
RAIL WITH 50'-6" BOXCAR	$ 873.59	$ 1,846.48	$ 2,830.00	$ 92.60	24	$ 2,720.08
LSV	$ 1,108.66	$ 1,001.86	$ 11,500.00		750	$ 2,110.52
AOE	$ 1,108.66	$ 9,059.40	$ 26,506.12		750	$ 10,168.06

APPENDIX C - EXAMPLE OF NUMERICAL RESULTS

The following is an example of the data points generated from the cost curve equations. This example is for transporting Harpoon missiles from NWS Earle to NWS Yorktown.

SOUTH COST CURVE DATA POINTS						
# MSLS	48-FT FLTBD	TRUCK CONT	RAIL CONT	RAIL BOXCAR	LSV	AOE
34	$ 4,239.68	$ 4,213.68	$ 5,642.68	$ 5,642.68	$ 13,610.52	$ 36,674.18
17	$ 6,959.76	$ 6,933.76	$ 8,362.76	$ 8,362.76	$ 15,721.04	$ 46,842.24
2[illegible]	$ 9,679.83	$ 9,653.83	$ 11,082.83	$ 11,082.83	$ 17,831.56	$ 57,010.30
41	$ 12,399.91	$ 12,373.91	$ 13,802.91	$ 13,802.91	$ 19,942.08	$ 67,178.36
34	$ 15,119.99	$ 15,093.99	$ 16,522.99	$ 16,522.99	$ 22,052.60	$ 77,346.42
48	$ 17,840.06	$ 17,814.06	$ 19,243.06	$ 19,243.06	$ 24,163.12	$ 87,514.48
41	$ 20,560.14	$ 22,027.74	$ 21,963.14	$ 21,963.14	$ 26,273.64	$ 97,682.54
48	$ 23,280.22	$ 24,747.82	$ 24,683.22	$ 24,683.22	$ 28,384.16	$ 107,850.60
34	$ 27,519.90	$ 27,467.90	$ 27,403.29	$ 27,403.29	$ 30,494.68	$ 118,018.66
10	$ 30,239.97	$ 30,187.97	$ 30,123.37	$ 30,123.37	$ 32,605.20	$ 128,186.72
17	$ 32,960.05	$ 32,908.05	$ 32,843.45	$ 32,843.45	$ 34,715.72	$ 138,354.78
12	$ 35,680.13	$ 35,628.13	$ 35,563.52	$ 35,563.52	$ 36,826.24	$ 148,522.84
33	$ 38,400.20	$ 39,841.81	$ 38,283.60	$ 38,283.60	$ 38,936.76	$ 158,690.90
17	$ 41,120.28	$ 42,561.88	$ 41,003.68	$ 41,003.68	$ 41,047.28	$ 168,858.96
48	$ 43,840.36	$ 45,281.96	$ 43,723.75	$ 43,723.75	$ 43,157.80	$ 179,027.02
16	$ 46,560.43	$ 48,002.03	$ 46,443.83	$ 46,443.83	$ 45,268.32	$ 189,195.08
17	$ 50,800.11	$ 50,722.11	$ 49,163.91	$ 49,163.91	$ 47,378.84	$ 199,363.14
12	$ 53,520.19	$ 53,442.19	$ 51,883.98	$ 51,883.98	$ 49,489.36	$ 209,531.20
10	$ 56,240.26	$ 57,655.87	$ 54,604.06	$ 54,604.06	$ 51,599.88	$ 219,699.26
20	$ 58,960.34	$ 60,375.94	$ 57,324.14	$ 57,324.14	$ 53,710.40	$ 229,867.32
2[illegible]	$ 61,680.42	$ 63,096.02	$ 60,044.21	$ 60,044.21	$ 55,820.92	$ 240,035.38
17	$ 64,400.49	$ 65,816.10	$ 62,764.29	$ 62,764.29	$ 57,931.44	$ 250,203.44
2[illegible]	$ 67,120.57	$ 68,536.17	$ 65,484.36	$ 65,484.36	$ 60,041.96	$ 260,371.50
2[illegible]	$ 69,840.65	$ 71,256.25	$ 68,204.44	$ 68,204.44	$ 62,152.48	$ 270,539.56
25	$ 74,080.33	$ 75,469.93	$ 73,847.12	$ 73,847.12	$ 64,263.00	$ 280,707.62
26	$ 76,800.40	$ 78,190.01	$ 76,567.20	$ 76,567.20	$ 66,373.52	$ 290,875.68
2[illegible]	$ 79,520.48	$ 80,910.08	$ 79,287.27	$ 79,287.27	$ 68,484.04	$ 301,043.74
28	$ 82,240.56	$ 83,630.16	$ 82,007.35	$ 82,007.35	$ 70,594.56	$ 311,211.80
2[illegible]	$ 84,960.63	$ 86,350.24	$ 84,727.43	$ 84,727.43	$ 72,705.08	$ 321,379.86
34	$ 87,680.71	$ 89,070.31	$ 87,447.50	$ 87,447.50	$ 74,815.60	$ 331,547.92
34	$ 90,400.79	$ 93,283.99	$ 90,167.58	$ 90,167.58	$ 76,926.12	$ 341,715.98
17	$ 93,120.86	$ 96,004.07	$ 92,887.66	$ 92,887.66	$ 79,036.64	$ 351,884.04
33	$ 97,360.54	$ 98,724.15	$ 95,607.73	$ 95,607.73	$ 81,147.16	$ 362,052.10
34	$ 100,080.62	$ 101,444.22	$ 98,327.81	$ 98,327.81	$ 83,257.68	$ 372,220.16
45	$ 102,800.70	$ 104,164.30	$ 101,047.89	$ 101,047.89	$ 85,368.20	$ 382,388.22
34	$ 105,520.77	$ 106,884.38	$ 103,767.96	$ 103,767.96	$ 87,478.72	$ 392,556.28
34	$ 108,240.85	$ 111,098.06	$ 106,488.04	$ 106,488.04	$ 89,589.24	$ 402,724.34
34	$ 110,960.93	$ 113,818.13	$ 109,208.12	$ 109,208.12	$ 91,699.76	$ 412,892.40
33	$ 113,681.00	$ 116,538.21	$ 111,928.19	$ 111,928.19	$ 93,810.28	$ 423,060.46
40	$ 116,401.08	$ 119,258.29	$ 114,648.27	$ 114,648.27	$ 95,920.80	$ 433,228.52
41	$ 120,640.76	$ 121,978.36	$ 117,368.35	$ 117,368.35	$ 98,031.32	$ 443,396.58
12	$ 123,360.84	$ 124,698.44	$ 120,088.42	$ 120,088.42	$ 100,141.84	$ 453,564.64
33	$ 126,080.91	$ 128,912.12	$ 122,808.50	$ 122,808.50	$ 102,252.36	$ 463,732.70
41	$ 128,800.99	$ 131,632.20	$ 125,528.58	$ 125,528.58	$ 104,362.88	$ 473,900.76
45	$ 131,521.07	$ 134,352.27	$ 128,248.65	$ 128,248.65	$ 106,473.40	$ 484,068.82
45	$ 134,241.14	$ 137,072.35	$ 130,968.73	$ 130,968.73	$ 108,583.92	$ 494,236.88
41	$ 136,961.22	$ 139,792.43	$ 133,688.81	$ 133,688.81	$ 110,694.44	$ 504,404.94
48	$ 139,681.30	$ 142,512.50	$ 136,408.88	$ [illegible]	$ 112,804.96	$ 514,573.00
48	$ 143,920.98	$ 146,726.18	$ 142,051.56	$ 142,051.56	$ 114,915.48	$ 524,741.06
34	$ 146,641.05	$ 149,446.26	$ 144,771.64	$ 144,771.64	$ 117,026.00	$ 534,909.12
34	$ 149,361.13	$ 152,166.33	$ 147,491.72	$ 147,491.72	$ 119,136.52	$ 545,077.18
52	$ 152,081.20	$ 154,886.41	$ 150,211.79	$ 150,211.79	$ 121,247.04	$ 555,245.24
34	$ 154,801.28	$ 157,606.49	$ 152,931.87	$ 152,931.87	$ 123,357.56	$ 565,413.30
12	$ 157,521.36	$ 160,326.56	$ 155,651.95	$ 155,651.95	$ 125,468.08	$ 575,581.36
55	$ 160,241.43	$ 164,540.24	$ 158,372.02	$ 158,372.02	$ 127,578.60	$ 585,749.42
6[illegible]	$ 162,961.51	$ 167,260.32	$ 161,092.10	$ 161,092.10	$ 129,689.12	$ 595,917.48
55	$ 167,201.19	$ 169,980.40	$ 163,812.18	$ 163,812.18	$ 131,799.64	$ 606,085.54
6[illegible]	$ 169,921.27	$ 172,700.47	$ 166,532.25	$ 166,532.25	$ 133,910.16	$ 616,253.60
34	$ 172,641.34	$ 175,420.55	$ 169,252.33	$ 169,252.33	$ 136,020.68	$ 626,421.66
55	$ 175,361.42	$ 178,140.63	$ 171,972.41	$ 171,972.41	$ 138,131.20	$ 636,589.72
61	$ 178,081.50	$ 182,354.31	$ 174,692.48	$ 174,692.48	$ 140,241.72	$ 646,757.78
61	$ 180,801.57	$ 185,074.38	$ 177,412.56	$ 177,412.56	$ 142,352.24	$ 656,925.84
34	$ 183,521.65	$ 187,794.46	$ 180,132.64	$ 180,132.64	$ 144,462.76	$ 667,093.90
61	$ 186,241.73	$ 190,514.54	$ 182,852.71	$ 182,852.71	$ 146,573.28	$ 677,261.96
55	$ 190,481.41	$ 193,234.61	$ 185,572.79	$ 185,572.79	$ 148,683.80	$ 687,430.02
55	$ 193,201.48	$ 195,954.69	$ 188,292.86	$ 188,292.86	$ 150,794.32	$ 697,598.08
61	$ 195,921.56	$ 200,168.37	$ 191,012.94	$ 191,012.94	$ 152,904.84	$ 707,766.14
55	$ 198,641.64	$ 202,888.45	$ 193,733.02	$ 193,733.02	$ 155,015.36	$ 717,934.20
55	$ 201,361.71	$ 205,608.52	$ 196,453.09	$ 196,453.09	$ 157,125.88	$ 728,102.26
10	$ 204,081.79	$ 208,328.60	$ 199,173.17	$ 199,173.17	$ 159,236.40	$ 738,270.32

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